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A GENERAL WAREHOUSE MODULE CONCEPTUAL DESIGN AND COST ANALYSIS.--ETC(U)
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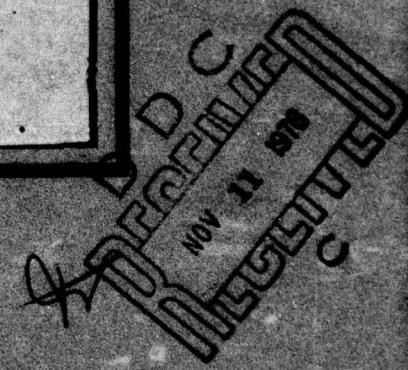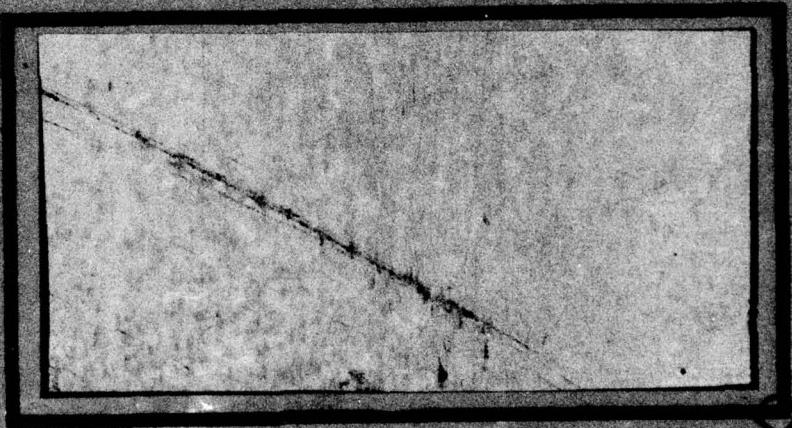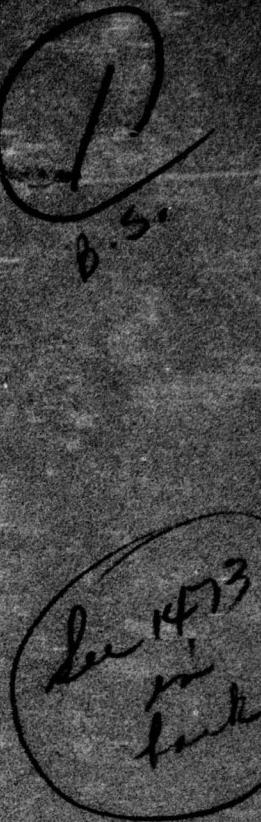
UNITED STATES AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY
Wright-Patterson Air Force Base, Ohio

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A GENERAL WAREHOUSE MODULE

CONCEPTUAL DESIGN AND COST ANALYSIS

(Executive Summary)

GCE/MC/76S-1   1976 Graduate Class
                     Civil Engineering/Facilities

A GENERAL WAREHOUSE MODULE

CONCEPTUAL DESIGN AND COST ANALYSIS

(Executive Summary)

DESIGN STUDY

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

1976 Graduate Class

Civil Engineering/Facilities

September 1976

The Air Force Institute of Technology (AFIT), School of Engineering, Graduate Civil Engineering/Facilities Class of 1976 (GCE-76S) developed a design concept for a general warehouse module as an integral component within the overall mission of the DODMDS. The executive summary, presented herein, is a brief synopsis of the main report text and appendices that has been submitted to DODMDS. The class members who participated in the development of the design concept are all United States Air Force (USAF) officers with the exception of one member who is a Royal Australian Air Force (RAAF) officer. The nine class members are listed below.

John T. High, III (Major, USAF)

Roland T. Alexander (Major, USAF)

Terence J. Carmichael (Squadron Leader, RAAF)

William A. Craig (Captain, USAF)

Don M. Inouye (Captain, USAF)

George H. Kotti (Captain, USAF)

Carl W. Lay (Captain, USAF)

John L. Mansfield (Captain, USAF)

Donald E. Teague, Jr. (Captain, USAF)

The design study of the general warehouse module was accomplished in partial fulfillment of the requirements for the degree of Master of Science. In producing the design study numerous individuals and organizations provided their time, their valuable technical assistance derived from years of experience in their respective disciplines, and, in many cases, unlimited patience. GCE-76S wishes to express its gratitude and sincere appreciation

to all persons who assisted in the development of this conceptual design.

In order to recognize a very special member of our "team effort", the entire class desires to acknowledge the persistence and attention to detail of our typist, Mrs. Margaret A. Teague.

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ABSTRACT

The conceptual development and design of a general warehouse module for the Norfolk, Virginia area was accomplished. A life-cycle cost analysis was made to furnish the Department of Defense with information to be used in a study of the Services' material distribution system. The design embraced civil, mechanical, and electrical engineering aspects of the facility. Various structural schemes were investigated with regard to feasibility and flexibility within a range of building heights from 30 to 60 feet. Alternative methods of satisfying energy requirements were analyzed with the aim of maintaining specified internal environmental conditions and accommodating anticipated electrical loads. Design of an associated electrical distribution network and lighting system were included. A comprehensive discussion of fire protection considerations is also presented. The design results and economic analysis indicate: (1) a braced frame steel structure is the most cost effective structural plan, (2) purchased power is cheaper than a total energy system for the projected operating schedule, (3) a primary selective-secondary selective electrical distribution system is required, (4) fire protection costs are a significant factor in the total cost, and (5) a 60 foot facility has the lowest cost per 1000 cubic feet of volume.

I. INTRODUCTION

The Graduate Civil Engineering/Facilities Class of 1976 (GCE-76S) selected a thesis project, proposed by the Department of Defense Material Distribution System (DODMDS) Study Panel, to investigate concepts for a general warehouse module. The specific purpose of DODMDS is to analyze current material distribution processes, and to identify future requirements worldwide. DODMDS will recommend alternatives to integrate, consolidate and standardize material distribution system functions and facilities. As a part of the study panel, the Engineering Analysis Task Group (EATG) was tasked to develop a plan to modernize existing facilities and construct new distribution depots as determined from the study. EATG developed general design criteria to meet the functional requirements of a new modular material distribution facility, and presented this information to the GCE-76S group.

Aim

The overall aim of the GCE-76S study group was to develop facility concepts for a general warehouse module within the guidelines specified by EATG. More specifically, however, EATG required facility cost data as an input to the DODMDS computer models which optimize and simulate the comprehensive DOD material distribution system. Thus a more immediate goal for GCE-76S was to produce realistic cost information for a range of facility configurations. A governing factor, in pursuing these aims, was to incorporate state-of-the-art concepts which reflect current industrial practice.

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Approach

To satisfy the broad range of parameters for the facility, and to produce a suitably comprehensive set of cost results within the limited time available, emphasis was placed on developing concepts rather than specific design detail. To limit the scope of the study, the Norfolk, Virginia site, one of five possible sites presented by EATG, was selected by GCE-76S as being representative in design parameters. Various systems were evaluated with a view to selecting those which best satisfied the projected functional requirements for the facility, and the determined engineering parameters for the Norfolk site. As a guide to this evaluation, existing large-scale material distribution facilities were inspected and a comprehensive study of current industrial practice was undertaken. Feasible systems were then analyzed using life-cycle cost evaluation. Component costs were based upon the best information available from industry. It is important to stress that the costs presented herein, represent only the cost of the basic facility structure and the associated internal energy systems. For instance, the study did not address the cost of material handling equipment, personnel support facilities, land, or site preparation.

Sequence of Presentation

The study encompassed the three major disciplines of civil, mechanical, and electrical engineering. A separate, but related study of fire protection and prevention was conducted concurrently. The report includes a discussion of these major topics, preceded by a description of the facility and concluding with a summary of significant cost results as follows:

Section II. Facility Description

Section III. Civil Engineering and Fire Protection

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Section IV.   Internal Energy Systems

Section V.   Cost Results

Section VI.   Conclusion

II. FACILITY DESCRIPTION

The general warehouse module is a 50 acre distribution center which is divided into a ten acre operating area, a ten acre mechanized storage area, and a 30 acre general storage area. The operating area is used for distribution processing to include receiving, packing, set and unit assembly, packaging, shipping, container assembly and manufacture, and maintenance support. The mechanized area is used as a bin and rack storage area containing automated material handling equipment. The general storage area is used for bulk storage. The building layout shown in Figure 1 was used for the study and was a concordant decision involving GCE-76S and EATG.

In addition to the three basic areas previously described, a one million cubic foot secure storage area and a bridge crane system are located within the facility. Also included in the distribution center concept is a one million cubic foot, geographically co-located freezer/cooler facility that is independent of the general warehouse module.

Several general design parameters were specified by EATG. The column spacings were set at 60 feet throughout the facility with the exception of the operating area, where the column spacing was reduced to support the additional load resulting from an overhead conveyor system. The usable storage height in the operating area was held constant at 30 feet while the storage heights in the mechanized and general storage areas were varied from 30 to 60 feet at ten foot increments. The four resulting facility configurations are referenced as the 30 foot building, the 40 foot building, the 50 foot building, and the 60 foot building. The floor loadings throughout the facility were varied from 1000 to 8000 pounds per square foot. A

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245'

FREEZER/COOLER (41,650 sq ft)

Volume = 1,000,000 cu ft

170'

150' **360'** **150'**

630'

OPERATING
AREA
(464,400
sq ft)

Volume = 13,932,000 cu ft

Height	Volume
30'	13,068,000 cu ft
40'	17,424,000 cu ft
50'	21,780,000 cu ft
60'	26,136,000 cu ft

330'

80'

MECHANIZED
AREA
(435,600
sq ft)

Height	Volume
30'	41,508,000 cu ft
40'	54,576,000 cu ft
50'	67,644,000 cu ft
60'	80,709,000 cu ft

480'

GENERAL
STORAGE
AREA
(1,383,600
sq ft)

510'

1320'
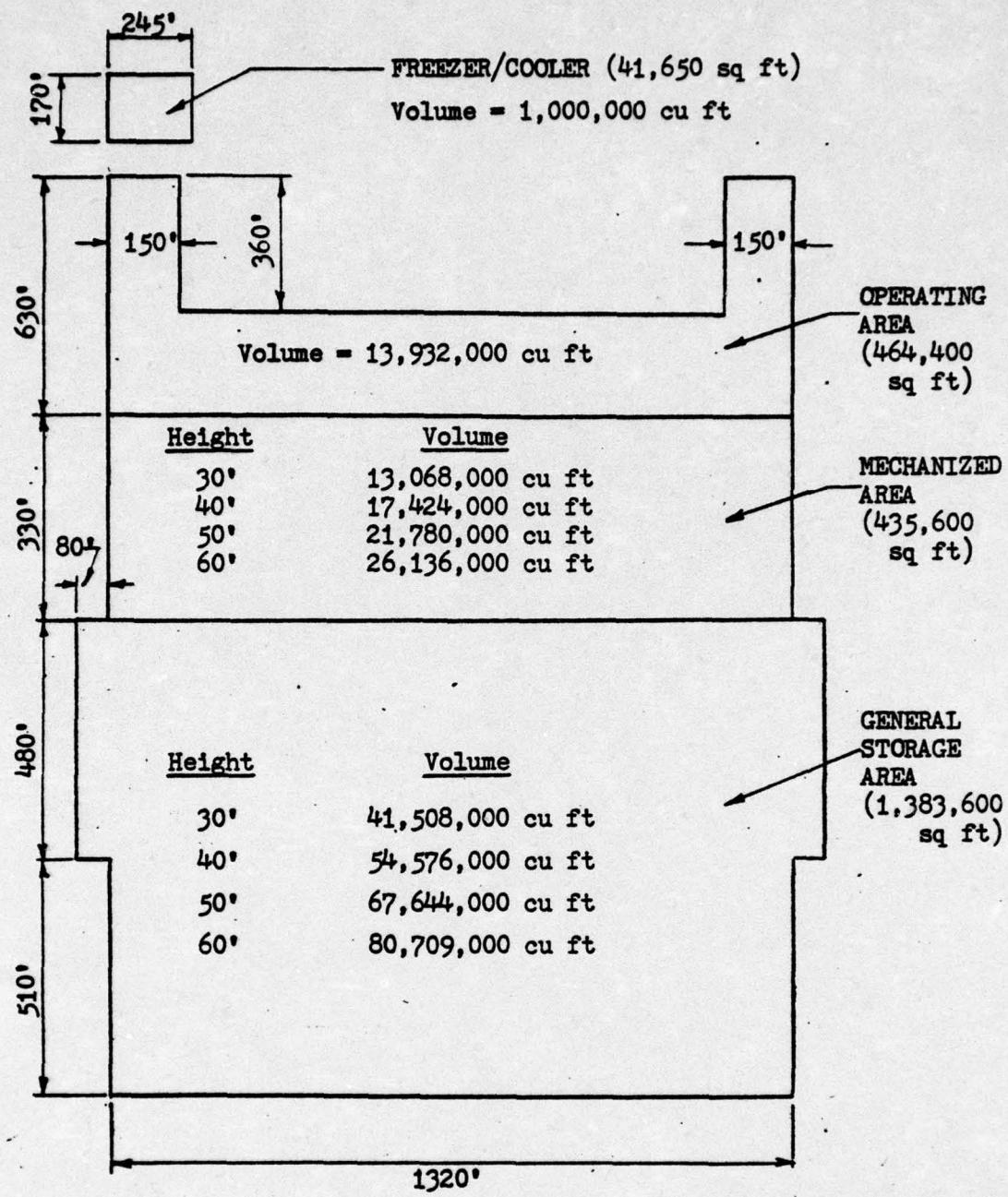
FIGURE 1 BUILDING LAYOUT

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temperature range of 65 to 80 degrees Fahrenheit was specified for the air-conditioned operating area. The mechanized area was also air-conditioned to insure the relative humidity will not exceed 50 percent. Ventilating fans were used in the unconditioned general storage area to keep the temperature below a maximum allowable temperature of 120 degrees Fahrenheit while the minimum allowable temperature specified for the general storage area was 55 degrees Fahrenheit.

III. CIVIL ENGINEERING AND FIRE PROTECTION

The Civil Engineering section of the project embraces the design of the structural frame, roofing and walls, and foundations and floor for the building shell. Specific designs for a bridge crane system and a secure storage area are included. A discussion of fire protection considerations including design of interior fire walls is also presented in this section.

Design Criteria

To accommodate a range of building concepts, as opposed to a specific design, a rather flexible approach to the study was necessary. However, the basic requirements of defining functional needs and engineering criteria, and then evaluating the systems which fulfilled those criteria, were adhered to. The functional requirements, input by EATG were described in Section II. Engineering criteria were investigated in detail for the Norfolk area specifically including design loads and soil conditions.

Design loads in addition to the live loads specified by EATG plus the dead load of the structure, included wind loads, earthquake loads and snow loads. The design wind speed for the Norfolk area of 105 miles per hour was converted to horizontal and vertical pressures on the structure. As the facility site was located in earthquake zone 1, earthquake loads were shown to have less significance in the structural design than wind loads. A snow load of 20 pounds per square foot was directly applied to the roof of the building.

Soil conditions in the Norfolk area were found to be generally poor for engineering applications. Soil bearing capacities were found to vary

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from less than 500 pounds per square foot to 4000 pounds per square foot.
Based upon information provided by the Naval Facilities Command (NAVFAC)
at Norfolk, soil bearing capacity of 1000 pounds per square foot was
assumed for the study. However, it must be emphasized that the actual site
selected will in all probability show a variation in soil properties which
can only be accurately interpreted after an exacting site soil survey.

Building Design

Having established engineering criteria, a general evaluation of
structural systems which could best accommodate the functional requirements
while meeting these engineering criteria was undertaken. Preliminary in-
vestigations were directed toward building layout, structural form, and
construction materials selection with a view to insuring flexibility and
economy in the final design. Selection of each component system within
the facility was determined by the ability to meet these criteria and the
related effect on other parts of the structure. Selected systems were then
analyzed in detail to insure feasibility in an integrated structure and to
provide an adequate basis for cost determination.

Structural Framing. The basic component of the structure was the
structural frame and considerable effort was expended on selection and
design of framing systems. The structural frame was required to support
other building dead loads, applied live loads and to provide the required
unrestricted clear space for internal functions. Various materials, in-
cluding timber, reinforced concrete, prestressed concrete and steel were
evaluated.

Standard structural systems were considered in conjunction with the

evaluation of these structural materials to allow for efficient application of material properties. The additional criteria of minimizing overall structural weight was recognized as desirable for the Norfolk site because of the presumed poor foundation soil properties.

A braced steel frame structure was selected as best fitting the prescribed parameters. The frame comprised steel columns supporting a welded Warren type truss roof structure. The roof structure was designed with six feet deep primary trusses spanning 60 feet in the longitudinal direction with purlin supporting three feet deep secondary trusses spanning 60 feet in the transverse direction. Secondary trusses are spaced at 30 foot intervals and a purlin spacing of six feet was selected. Wind loads were transferred primarily through the first four exterior bays of the structure to the foundations. A flat roof profile was selected as most economical.

Exterior Walls and Roofing. Similar criteria were applied to the the selection of exterior walls and roofing as were used in evaluation of structural framing. Additionally, those surfaces had to provide the heat transfer coefficients (U value), required for efficient mechanical operation. The desirability of providing security along the building perimeter was also recognized by GCE-76S.

The selected exterior wall was a composite system consisting of concrete tilt slab in the lower 20 feet and steel sandwich panel up to the roof line. Use of concrete tilt slab for the lower section was cost effective to the 20 foot height, provided the added benefit of securing the perimeter, plus reducing the wind load taken by the column and column footings. A 7.5 inch thickness of concrete tilt slab combined with 1.5 inches of insulation provided the required U value. The steel sandwich panel provided

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more economical installation above 20 feet and was selected to ensure adequate insulation.

Selection of roofing materials was based upon providing a light-weight, weather-proofing system with the required heat transfer properties and consistent with designed purlin spacings. The system was comprised of a 20 gauge steel deck covered with rigid fiberglass and rigid urethane insulation, and topped with an aggregate covered four ply built-up roof. To provide fire protection, the steel was topped with fiberglass insulation prior to covering with urethane.

Foundations and Floor. Foundations were required for the building shell, interior and exterior walls, and the bridge crane system. Conventional reinforced concrete spread footings were designed for interior columns where only gravity loads were carried. The exterior wall footing was designed as a continuous strip footing of reinforced concrete. Because of the poor bearing capacities assumed for the Norfolk soil, pile foundations were found to be structurally necessary and/or more economical where large moments were to be transferred to the foundations. As a result, column foundations for the first four bays around the building perimeter were designed as pile supported footings. Also, because of the overturning pressures on interior fire walls pile supported strip footings were required. In addition, the bridge crane foundations were required to support large moments and pile foundations were required.

The building floor was designed to meet anticipated intensity and frequency of traffic loads, plus to provide for uniform live loads of 1000 to 8000 pounds per square foot. For the assumed allowable soil bearing capacity of 1000 pounds per square foot only the 1000 pounds per square

foot live load could be supported by a slab-on-grade construction. Higher floor loads were designed as pile supported two-way slabs.

Bridge Crane. An integral part of the overall warehouse concept included the design of a bridge crane system. This system incorporated bridge cranes, crane frame and foundation support on either side of the general storage area. A double rail system was selected in order to reduce the overall length of the crane structure. The resulting crane frame was designed as a rigid steel structure spanning 70 feet with columns spaced at 30 feet.

Secure Storage. A secure storage area was required within the facility to provide storage for material up to and including secret classification. A masonry storage vault 180 feet square and 34 feet high, with an eight inch lightweight concrete ceiling was designed to meet this objective.

Fire Protection

Fire protection was an integral part of the facility concept. Methods of protecting the structure, including prevention of an outbreak of fire and containment of fire, were established. A building equipped with fire protection devices is still exposed to a degree of risk involving personnel, commodities, equipment, and the structure. To reduce this risk, maximum fire areas of 80,000 square feet, separated by fire walls with a six hour fire rating are recommended.

Fire walls were designed for incorporation in the mechanized and general storage areas of the warehouse. The walls were designed as non-load bearing reinforced masonry structures to a height of three feet above the roof line to provide adequate structural separation. The controlling design force was a ten pounds per square foot fire pressure below the roof

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line and a design wind load for the three foot parapet above the roof line.

A wet-pipe water sprinkler system with 100 percent area coverage was selected. In-rack sprinklers are required for adequate protection where storage heights exceed 25 feet. Although water sprinklers do not guarantee extinguishing a fire, they serve to contain a fire until professional fire fighting techniques can be employed.

IV. INTERNAL ENERGY SYSTEMS

The efficient use of energy is an important consideration when de-
signing a new facility. GCE-76S developed a design concept and preliminary
cost estimates for internal energy systems based on the design parameters
provided by EATG. The internal energy system consists of the electrical
and thermal energy systems required to support the facility mission.

In order to develop a design concept, the electrical loads generated
by the material handling equipment, the lighting system, and other supporting
systems were determined while the heating, ventilating, and air conditioning
loads were derived from the external and internal environmental conditions.
After determining the internal energy requirements, several typical thermal
and electrical energy distribution systems were evaluated. Commercial
power, total energy, and solar energy systems were investigated in conjunc-
tion with the various energy distribution systems. The internal energy
systems with the lowest life cycle costs were selected. The design and
cost results are based upon the design parameters specified by EATG.

Lighting Systems

The aim of the lighting design was to select an economical lighting
system that would provide an adequate and uniform level of illumination
throughout the life of the facility. Flourescent, mercury vapor, metal
halide, and high pressure sodium lighting systems were evaluated. The
high pressure sodium lighting system was selected as having the lowest
life cycle cost. A busway lighting circuit was found to be economically
competitive with a wire in conduit circuit. The busway circuit was se-
lected to provide for flexibility in the lighting design should the internal

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configuration of the facility change.

The emergency lighting system selected consists of a quartz lamp used in conjunction with the high pressure sodium luminaire. A separate wire in conduit circuit is provided for the emergency lighting system which is powered by a quick start diesel emergency generator.

Electrical Distribution System

In order to provide a high degree of reliability and maintainability, a primary selective-secondary selective electrical distribution system was specified by EATG. After evaluating the electrical load data, the facility was divided into ten electrical distribution zones, each containing an area substation. A typical primary distribution network from the facility service entrance to each area substation was designed and analyzed. A detailed design of a secondary distribution network from the area substation to the specific area loads was not accomplished due to the lack of a definite facility layout. However, cost estimates were provided for a typical secondary distribution system along with the cable, transformers, and switchgear required for the primary distribution networks.

Energy Requirements

Using the design parameters and specifications provided by EATG and the results of the lighting study, GCE-76S analyzed the thermal and electrical energy requirements for the facility. This study was conducted by modeling the warehouse operations with the American Gas Association's energy analysis computer simulation, ECUBE75. Input to the simulation included the projected personnel, material handling equipment, and operating hour requirements provided by EATG. Also input were building geometry, locations, insulation, ventilation, and temperature data. In addition,

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weather information for each hour of the year for the Norfolk, Virginia area was input. Using this information, ECUBE calculated the thermal and electrical energy requirements for each hour of the year. The computer output included values for the total consumption of heating, cooling, and electrical energy.

Also included were values for the peak heating, cooling, and electrical loads. This output showed that for a well insulated warehouse, heating was not required except to offset the perimeter losses on cold days. At all times, the heat produced by lights, motors, and people was sufficient to keep the facility above 65 degrees Fahrenheit. The hourly values for the cooling loads were used to evaluate air conditioning systems designed to meet the facility requirements.

Energy Source Selection.

A cost comparison of building system and operating costs for three sources of energy to power the facility electrical loads and mechanical equipment was studied by GCE-76S. Energy sources studied included solar collectors, commercial electrical power, and total energy power generation stations integrated with the facility design. A systems analysis approach based on integrated facility designs was used to accomplish the cost evaluations.

Solar systems were analyzed as a power source for building cooling systems. Cost results were evaluated in comparison to conventional electric chiller systems. Both stationary flat plate collectors and automatic tracking collectors were considered. These systems were evaluated as the sole source of energy input and as a supplement to commercial power. Results of this study show that where solar energy was used as a sole source,

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the cost ratio of solar to commercial power is approximately four to one. When solar was used as a supplementary source, the ratio was reduced to approximately two to one. All solar systems had higher costs and were not competitive with commercial power systems.

The costs for meeting the facility energy requirements through the use of commercial power were evaluated by designing eight mechanical systems for each of the four warehouse buildings. These systems were sized to meet the thermal loads calculated by the ECUBE energy requirements simulation. Using the partial load characteristics for the equipment selected, the ECUBE equipment selection program determined the electrical consumptions and operating hours for the mechanical systems. From this information, the operating and maintenance costs for these systems were computed. These costs were added to the costs of the electrical energy required to operate the building lighting and material handling equipment. An annual cost value for each commercial power system studied was calculated based on the installed system purchase price, the yearly operating and maintenance costs, and the yearly costs for electricity. For each of the four buildings, the system with the lowest annual cost value was selected as the best commercial power system.

The GCE-76S study included the evaluation of total energy systems to meet the facility thermal and electrical loads determined in the ECUBE energy analysis. These systems were designed on the basis of using generators installed at the warehouse site to produce the electric power for the facility with the exhaust heat from the generators being used to power absorption chillers which supply the necessary air conditioning. Gas

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turbine, gas turbine/steam turbine, and diesel generators were evaluated. An absorption chiller system was designed to match the needs of each of the generator sets. Seven total energy systems were evaluated for each of the four buildings. Using the partial load operating characteristics of the generators and chillers, the fuel requirements and operating hours for each of these systems, necessary to meet the projected energy require- ments, were calculated by the ECUBE equipment selection simulation. These values were used to compute the operating and maintenance costs for the total energy systems. Annual cost values were computed for each of the systems evaluated based on the installed capital costs and the computed operating and maintenance costs. For each of the four buildings, the system with the lowest annual cost value was selected as the best total energy system.

A comparison of the projected annual cost values for the selected commercial power systems and the selected total energy systems results in the determination that commercial power is less expensive. The actual cost differential was approximately ten percent. In order to validate these results, a sensitivity analysis of the effects of changing fuel and electricity prices was conducted. Results of this analysis showed that by varying the projected prices for fuel and electricity, within the limits of current market prices in the Norfolk, Virginia area, total energy systems could be shown to be as much as ten percent cheaper than commercial power systems. These results indicate that the annual cost values computed in this study are appropriate to either commercial power or total energy applications and can be used in the DODMDS warehouse studies. However, before the energy source selection is made for a specific site, a careful

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analysis of the projected costs and inflation rates for electricity and fuel should be conducted. The results of this report should then be modified to reflect the projected energy costs determined by such a study.

Energy Monitoring and Control System

An Energy Monitoring and Control System (EMCS) allows the facility user to monitor and control various systems from a central location. Such a system can reduce operating costs by optimizing energy consumption and saving manpower dollars. It is necessary to have a specific facility design in order to define EMCS requirements and determine an accurate EMCS cost. Since a specific design was not available, cost estimates were provided for a typical EMCS within a range of 500 to 5000 control and monitoring points. The annual costs for the respective EMCS ranged from $59,510 to $301,367. When a specific design has been determined, it will be necessary to perform a thorough economic analysis to maximize the difference between the annual cost of the system and the annual savings achieved by using an EMCS.

Freezer/Cooler

Cost estimates for a geographically co-located, independent freezer/ cooler facility resulted from the GCE-76S effort. These estimates were based on a conventional freezer/cooler design with approximately one million cubic feet of storage space. EATG requirements specified one-third of the volume as freezer and two-thirds of the volume as cooler. Structural costs were extracted from the data base developed by the study on the general warehouse module. A lighting study was conducted to develop a suitable lighting design. Cooling loads, facility energy requirements, and insulation requirements were calculated by using the computer simulation ECUBE. Cost estimates resulting from these studies are shown in Table 1.

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TABLE 1

FREEZER/COOLER COST ESTIMATES

($)

	FREEZER	COOLER	LOADING DOCK	TOTAL
Capital	522,360	760,146	166,337	1,448,843
Yearly Energy And Maintenance	29,399	31,193	1,455	62,047
Annual Cost Value	86,947	114,938	19,780	221,665

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Internal Energy Cost Data Sensitivity Analysis

Analysis of the results shows that the most important variable in determining the "dollars per 1000 cubic foot" cost values is the assumed installed level of energy consumption. The capacities, expressed as installed kilowatt load per cubic foot, used to compute the given cost estimates, are detailed in the main report text. These capacities, power levels, were calculated by adding the peak kilowatt loads for the building lights, material handling equipment, and HVAC equipment for each of the three building functional areas (operating, mechanized, and general storage). Plotting the building cost values versus the associated power level values shows that there is a proportional relationship between cost and the kilowatt requirements. This relationship is presented in the main report text and the following figure is a typical representation of the proportional relationship.
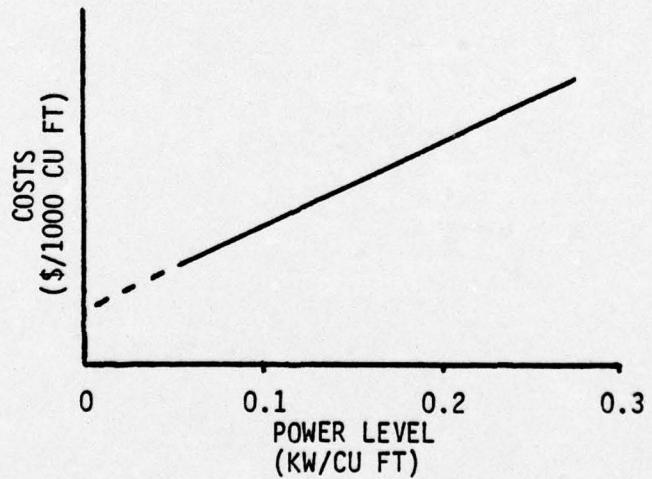

FIGURE 2 TYPICAL REPRESENTATION OF COSTS VS. POWER LEVEL

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V. COST RESULTS

An important result of the study was the development of meaningful cost data for use by EATG in comprehensive studies of facility functional concepts. The costs produced are considered the best available and are consistent with those industrial systems investigated. To allow ready access to this data, and to demonstrate the sensitivity of the costs to building and functional systems, cost data is presented in three parts: capital costs, yearly costs, and annual costs.

Capital Costs

Tables 2 and 3 present capital costs for representative facilities as a function of building height and functional area (operating, mechanical, and general storage). Total capital cost is shown in Table 2. Table 3 transforms these total costs into dollars per 1000 cubic feet of usable storage. Representative component costs, including pertinent structural systems and individual internal energy functions, are shown in Table 4 as capital costs contributing to the total cost for the four building heights investigated.

It should be noted that specific parameters were selected in some cases to produce the tables and these are noted below each table. As a result, cost sensitivity may extend beyond the tabulated values. For example, the cost of providing a desired floor loading is sensitive to soil bearing capacity and the cost of mechanical equipment is sensitive to the selection of total energy or commercial power as an energy source.

Yearly Costs

Yearly operation and maintenance costs are presented in a similar

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format showing cost results as a function of building heights and functional areas in Tables 5 and 6. Table 5 shows total yearly cost and Table 6 shows the yearly cost in dollars per 1000 cubic feet of usable storage. Table 7 breaks out the total yearly costs into component costs to show sensitivity. It should be noted that approximately 80 percent of the internal energy systems annual cost can be attributed to energy requirements.

Annual Costs

In order to provide a common basis for evaluation of overall facility costs, including capital and yearly costs, annual cost data was produced. Annual costs were based on the end of year convention assuming a 25 year facility life and using a ten percent interest rate. Table 8 presents the total combined annual costs and Table 9 shows these costs converted to dollars per 1000 cubic foot of usable storage space.

TABLE 2

TOTAL CAPITAL COST *

($)

BLDG HEIGHT (FT)	OPER AREA	MECH AREA	GEN STOR AREA	TOTAL
30	5,156,952	5,429,071	14,658,588	25,244,611
40	5,214,900	5,689,484	16,489,496	27,393,880
50	5,269,956	6,064,094	18,081,879	29,415,929
60	5,291,375	6,428,745	20,136,587	31,919,707

TABLE 3

CAPITAL COST *

($ PER 1000 CUBIC FEET)

BLDG HEIGHT (FT)	OPER AREA	MECH AREA	GEN STOR AREA	TOTAL
30	374.50	407.65	354.44	370.37
40	378.91	321.59	302.97	319.80
50	383.10	274.68	267.91	285.23
60	384.73	245.61	249.91	264.66

* Based on allowable floor loading of 1000 pounds per square foot and mechanical equipment selection for commercial power.

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TABLE 4

COMPONENT CAPITAL COSTS

($)

BUILDING HEIGHT (FT)

	30	40	50	60
Roofing	5,480,640	5,480,640	5,480,640	5,480,640
Structural Framing	5,962,348	6,613,029	7,312,268	8,001,493
Floor *	2,906,568	2,906,568	2,906,568	2,906,568
Foundations	1,208,973	1,254,108	1,278,948	1,309,308
Exterior Walls	996,921	1,140,273	1,283,625	1,426,977
Interior Walls	3,419,372	4,836,000	5,886,607	7,683,925
Bridge Crane	1,258,898	1,258,898	1,258,898	1,258,898
Secure Storage	308,351	308,351	308,351	308,351
Lights	592,195	635,709	685,720	565,653
Electrical Distribution System +	907,886	843,114	843,281	883,513
Centrifugal Chillers +	275,600	254,700	265,200	265,200
Pumps +	60,849	57,389	58,316	58,558
Cooling Tower +	86,000	76,000	76,000	77,000
Boilers +	18,513	22,236	22,236	30,335
Air Handling Units	320,334	276,348	287,438	314,800
Ducts And Piping	238,374	224,259	221,055	232,000
Fans	236,848	243,430	277,950	334,050

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TABLE 4 CONTINUED

	30	40	50	60
Backup Generators +	872,513	869,400	869,400	698,010
Uninterruptable Power System	93,428	93,428	93,428	93,428
Total	25,244,611	27,393,880	29,415,929	31,919,707

* Floor costs were based on an allowable floor loading of 1000 pounds per square foot.

+ Mechanical equipment costs were based on selection of commercial power.

TABLE 5

TOTAL YEARLY OPERATIONS AND MAINTENANCE COSTS *

($)

BLDG HEIGHT (FT)	OPER AREA	MECH AREA	GEN STOR AREA	TOTAL
30	157,680	304,227	115,260	577,167
40	159,651	236,359	135,384	531,394
50	158,863	199,815	153,549	512,227
60	160,177	171,864	159,168	491,209

TABLE 6

YEARLY OPERATIONS AND MAINTENANCE COSTS *

($ PER 1000 CUBIC FEET)

BLDG HEIGHT (FT)	OPER AREA	MECH AREA	GEN STOR AREA	TOTAL
30	12.00	21.95	2.94	8.72
40	12.15	12.79	2.59	6.34
50	12.09	8.65	2.35	5.04
60	12.19	6.20	2.03	4.12

* Operations and maintenance costs based on selecting commercial power.

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TABLE 7

COMPONENT YEARLY COSTS

($)

BUILDING HEIGHT (FT)

	30	40	50	60
Lights *	23,850	25,026	26,147	23,493
Centrifugal Chillers	48,099	43,872	35,676	32,309
Pumps *	770	770	770	770
Cooling Tower	2,000	2,000	2,000	2,000
Air Handling Units *	10,640	9,360	10,640	11,920
Fans *	3,930	3,300	3,270	3,930
Uninterruptable Power System	2,645	2,645	2,645	2,645
Building Yearly Electrical Consumption	485,233	444,421	431,079	414,142
Total	577,167	531,394	512,227	491,209

* Yearly costs include maintenance cost only. Associated energy costs are included under Building Yearly Electrical Consumption.

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TABLE 8

TOTAL ANNUAL COST*

($)

BLDG HEIGHT (FT)	OPER AREA	MECH AREA	GEN STOR AREA	TOTAL
30	725,821	902,348	1,730,197	3,358,366
40	734,177	863,169	1,952,032	3,549,378
50	739,454	867,896	2,145,630	3,752,980
60	743,128	880,119	2,377,616	4,007,803

TABLE 9

ANNUAL COST*

($ PER 1000 CUBIC FEET)

BLDG HEIGHT (FT)	OPER AREA	MECH AREA	GEN STOR AREA	TOTAL
30	53.26	66.86	41.99	49.52
40	53.89	48.22	35.97	41.57
50	54.30	38.91	31.87	36.46
60	54.58	33.26	29.56	33.28

* Annual costs are based on 25 year life, 10% interest rate, and end of year convention.

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VI. CONCLUSION

This engineering study of a general warehouse module has resulted
in a number of related concepts which can be integrated to provide a total
facility which meets the needs of EATG. Evaluation of systems which would
best meet the projected functional requirements of the facility, while
achieving economy and incorporating contemporary equipment and structural
systems, was emphasized. The end result is not so much a specific building
design, but rather a comprehensive set of data which can be interpreted to
provide engineering costs related to a range of functional configurations.

Although no attempt has been made to design or cost specific details,
the resulting concepts are considered to give a sound evaluation of the
feasibility of practical state-of-the-art systems, the sensitivity of the
overall facility costs to the selection of various systems, and an input
of cost magnitude to the complete DODMDS study. The application of the
results obtained within the limits prescribed should result in a valuable
contribution to the final selection of an economic and functionally optimized
facility.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The conceptual development and design of a general warehouse module for the Norfolk, Virginia area was accomplished. A life cycle cost analysis was made to furnish the Department of Defense with information to be used in a study of the Service's material distribution system. The design embraced civil, mechanical, and electrical engineering aspects of the facility. Various structural schemes were investigated with regard to feasibility and flexibility within a range of building heights from 30 to 60 feet. Alternative methods

over

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9. Fire Protection System
Pile Supported Floors
Moment Resisting Foundations
Tilt Slab Walls
Bridge Crane System
High Pressure Sodium Lighting
Freezer/Cooler Area
Roofing
Energy Monitoring and Control System
Heating, Ventilation and Air Conditioning (HVAC) Loads

20. of satisfying energy requirements were analyzed with the aim of maintaining specified internal environmental conditions and accommodating anticipated electrical loads. Design of an associated electrical distribution network and lighting system were included. A comprehensive discussion of fire protection considerations is also presented. The design results and economic analysis indicate: (1) a braced frame steel structure is the most cost effective structural plan, (2) purchased power is cheaper than a total energy system for the projected operating schedule, (3) a primary selective-secondary selective electrical distribution system is required, (4) fire protection costs are a significant factor in the total cost, and (5) a 60 foot facility has the lowest cost per 1000 cubic feet of volume.